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LAMONT GEOLOGICAL OBSERVATORY

PALISADES, NEW YORK

CIRCULATION NEAR THE SOUTHERN BERRY ISLANDS, BAHAMAS

Report prepared by: Bernard Katz

Technical Report No. CU-23-65 to the Atomic Energy Commission
Contract AT(30-1)2663

July, 1965

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ABSTRACT

Dye tracers were used in the Bahamas to study circulation in the southern part of the Berry Island group and near New Providence Island. Current velocities were measured using aerial photographs of dye patches in time series to obtain net displacements as small as 0.1 nautical miles. The use of dye tracers also provided comparative estimates of mixing on the shelf and information on the exchange of water between the banks and the Tongue of the Ocean.

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METHODS AND RESULTS

From July 3rd through July 7, 1963 a circulation study was conducted in the southern part of the Berry Islands near Frazers Hog Cay, using rhodamine B, a red organic dye, to tag masses of water. The movement of the dyed water was observed and photographed from an airplane. Most of the photographs were in color since the shallowness and clarity of the water and the great wealth of bottom detail would have made it difficult to separate the dye patches from the bottom features on black and white film.

The Berry Islands are a hook-shaped chain of wooded cays with heights up to about 60 feet lying at the northern end of the Tongue of the Ocean (TOTO). The southern and eastern edge of the bank on which these islands lie is very steep, especially the southern edge, which forms the northern boundary of the TOTO. Within the hook, largely to the west of the islands, the depths are three fathoms or less, and there is a great variety of bottom types.

A map of the bottom features in the area was prepared in 1962 by Dr. John Imbrie and Hugh Buchanan. By plotting on this map the positions of the dye patches at various times, as determined from the photos, it was possible to obtain the average velocity between positions. Figure 1 is a copy of this map showing the starting place and time of each of the eight dye releases. For the last one, number eight, thirty gallons of fluid were released; for each of the others about

fifteen gallons were used. The resulting dye patches remained observable for a period of from two to four days after release, depending upon the area through which they moved.

The sequence of positions and shapes of each dye patch are shown in Figures 2 through 9. The different positions of each dye patch are numbered; and for each position the corresponding time and the velocity between positions is shown in a table for that patch drawn on the figure. The currents are mainly tidal, and the drawings which accompany each table show dye patch positions during one flood or ebb only. These figures are presented in overlay form because on most of the map there was already so much detail that more could not be included with any clarity. It was felt that reproducing the map with less detail, so as to leave room for the inclusion of the dye patch shapes, would have been self-defeating. The overlays can be aligned with the area map by means of the two core stations (778k and 784v) and South Stirrup Cay, which have been included on each overlay.

The positions of the dye patches could be determined quite accurately from the photographs, as could their shapes, except in the very latest stages when the dye had become so tenuous that the boundaries of the patches could not be clearly discerned. The velocities were obtained by choosing a point within each patch which represented either its "center" or its apparent region of highest concentration, taking the distance between two successive points, and dividing by the elapsed

time. As long as the dye patch remained small compared to the distance it had moved and of fairly regular shape, there was little ambiguity about the points chosen and the values given for the velocity are fairly precise. When the dye patches had become large and irregular, with no apparent area of highest concentration, another feature of the dye patch was chosen, as, for example, a leading edge. Velocities obtained in this way are, of course, somewhat less precise. In the final stages of patch #VIII even this was impossible, and no evaluation of velocity is given. To obtain an estimate of the precision of these velocity measurements, the whole process of obtaining the velocity was repeated from the beginning (i.e. from the locating of positions on the map) for about half of the measurements. In all cases the difference obtained was less than 0.1 knots. The slack water periods, during which the currents reversed, lasted from several minutes to about an hour, depending on location, and were preceded and followed by a period of low velocity. Since the interval between photos averaged about fifteen minutes, no significant velocity error was introduced by current changes occurring between pictures.

Table 1 shows the wind conditions during these experiments.

TABLE 1 - WINDS

Date	Time	Velocity	Direction
July 3, 4, 5		Occasional breezes less than 2k	
July 6	1530	5-7k	306°
	1600	5k	310°
July 7	0915	9k	200°
	1005	5-10k	215°
	1530	10k	300°

By July 6 patches #I and II had become too tenuous for observation, so the effects of the wind in this area can only be guessed. The effects on the other dye patches seem to have been rather slight. The higher winds of July 7 had a pronounced effect, in that the whole circulation pattern in the area of patches #V and VI was changed. These two patches, which had previously converged upon each other during the flood and diverged during the ebb, now both moved off in an easterly direction.

The movement of patch #I reveals that, while the flooding tidal current in area of release sets towards the northeastern end of the Fish Cays and the ebbing current sets in roughly the opposite direction, there is net northwards drift of about one mile per day in this area. Also, the paths of dye patches #III and IV show a slight counter-clockwise rotation from one

flood to the next. It is believed that this rotation is the result of a net northward drift in this area of about two-thirds of a mile per day.

Figures 10 and 11 show the direction and maximum velocities of the tidal currents when the wind is negligible.

TIDES

The tides in the Bahamas are semi-diurnal at all times. H. O. Publication #21, "Sailing Directions for the West Indies", states that, when the moon is at its greatest northern or southern declination, the tides are diurnal; however, the "Yachtman's Guide", an official publication of the Development Board, Nassau, Bahamas, states, and recent measurements indicate, that in the Bahamas there are always two highs and two lows during a period of about one day with a varying inequality between them. The currents in the Bahamas are mostly tidal, but are strongly influenced by the wind.

Our experiments were made at a time when the moon was near its greatest southern declination; but because observation was restricted to daylight hours, our data do not reveal whether the tidal current changed once or twice. On each day a low water slack current was observed; and in the first few days of the experiment, when this slack was observed about mid-day, photographs taken in the early morning showed an acceleration of the flood current and those taken in the late afternoon showed a deceleration of the ebb. Thus, if the tide

were diurnal at this time, the high water slack current would have had to be about 12 or 13 hours in duration. However, such a prolonged slack water is not impossible where the tidal inequality is large.

H. O. Publication #21 lists the establishment for Nassau as 7 hours 22 minutes and that for the Berry Islands as 8 hours 30 minutes average. Since the moon crosses the local meridian of the Berrys about 1 2/3 minutes after it crosses the local meridian at Nassau, the tides at the Berry Islands would, therefore, lag those at Nassau by about 70 minutes. However, according to the "Yachtsman's Guide", the tides in the Berry Islands (at Whale Cay) lag those at Nassau by only 40 minutes. Unfortunately, our data can provide no clue as to how this difference should be resolved.

EXCHANGE AND MIXING

The Bahama Banks, in general, can be characterized as an area where little mixing takes place between adjacent water bodies in areas where the flow is not greatly disturbed by islands. For example, patches #III and IV, placed only 1/2 mile apart, retained their individual identities for more than two days even though they achieved lengths of up to 3/4 mile and flowed over a path length of about three miles. By comparison, two patches, involving similar quantities of dye, which were placed 1/2 mile apart in the New York Bight, fused together within 4 1/2 hours and had virtually disappeared

from sight 5 1/2 hours after release.

As expected, the dye became attenuated more quickly in areas where the velocity was higher. In the area of patches #V and VI, where the maximum velocity was only 0.3 kts., the concentration was still quite heavy 2 1/2 days after release, while in the area of patches #III and IV, where the maximum velocity was 0.6 kts., the dye patches appeared as two pinkish regions of water two days after release.

The contraction of dye patches #III and IV towards the end of the flood can be attributed to the piling up of the water within the island chain. Patches #V, VI, and VII also showed evidence of this piling up by the distortion of their shapes just prior to the high-water slack.

The only two of these experiments near the edge of the bank were #III and IV, which approached to within 1 1/2 miles of the 100-fathom contour on the ebb and moved inwards to about 4 1/2 miles from the 100-fathom contour on the flood. Since the flow in this area follows a streamlined pattern and the streamlines near the edge of the bank are perpendicular to it, most of the water which flows onto the shelf during the flood must return to the TOTO on the next ebb, only a small portion of it remaining on the banks to account for the slight northward drift.

Work done in April 1964 at the edge of the Eastern Great Bahama Bank in the vicinity of South West Reef (77°31'W, 24°53'N) is of interest when considering the mixing of shelf

water with TOTO water. The major difference between this area and that of the Berry Islands is that here the drift is westward (Busby and Dick, 1964), hence from the shelf to the TOTO, whereas in the Berrys it is northward from the TOTO to the shelf.

On a flight over the area on April 8 a slick, composed mostly of sargassum and oil, was noticed running parallel to the edge of the bank. The water was of a slightly different color on either side of this slick, being darker green on the shoalward side. During the ebb this slick remained right at the edge of the bank, but during the flood it moved inwards over the shallows.

A dye patch made on April 8 in shallow water 1/2 mile from the edge, during the ebb at about two hours before the turning of the tidal current, approached the edge at an angle of about 45° until it met the slick. By this time the tide had turned, and both the dye patch and the slick were moving back over the shallows. The patch had become somewhat flattened against the slick and had a very sharp edge coincident with it. The slick appeared to mark a boundary through which the dye could not penetrate.

On the following day, also during the ebb, a patch of yellow dye was placed at the edge of the bank in deep water. This spread along the edge of the bank and out over the deep water, but not over the bank. Again the slick, which was at the edge of the bank, seemed to form a boundary for the dye.

About twenty minutes after release of the yellow dye a similar quantity of red dye was released about two miles to the east in shallow water. This latter patch moved rapidly westward until it reached the edge of the bank, where it sank beneath the yellow dye and vanished, except for a very small amount that appeared on the northern end of the yellow patch. When the tidal current turned, the slick began to move eastward over the shallows and yellow dye began to spread over the shallow behind it. The wind during these experiments was from the southeast, and the dye patches showed a slight northerly drift.

It has been known for some time that the shoal water, due to its higher salinity, is denser than the surface water of the TOTO and is probably the source of the lenses of high salinity water that appear at intermediate depths in the TOTO. In fact, the density of the shoal water is about the same as that found at 175 meters in the central TOTO (Ridley, 1962). This water sinks upon reaching the edge of the bank, and the convergence thus produced generates the slick, which remains at the edge of the bank while the tide is ebbing. On the flood, surface water from the TOTO moves over the bank, and the slick moves inwards and probably breaks up after some time. The dye patch of April 8 apparently reached the edge just before the tide turned.

The difference in water color on either side of the slick and the behavior of the dye indicate that along the eastern edge of the TOTO there is very little dilution of shelf water

by TOTO water during a tidal cycle, and that all the water that moves onto the shelf in this area during the flood is returned to the TOTO during the following ebb.

However, the water flowing off the bank during the latter part of the ebb had a salinity of 37 o/oo or greater, while the surface water of the TOTO had a salinity of 36.6 o/oo (Costin, 1965). These values are in good agreement with measurements made in the spring of 1960 (Ridley, 1962). Busby and Dick (1964) report 18cm evaporation for the month of April, 1963. Over a single tidal cycle this rate of evaporation could increase the salinity of shelf water by only 0.01 o/oo; therefore, at least in the latter part of the ebb, the water flowing off the shelf is not TOTO water which had moved on during the preceding flood, but water which had been on the shelf for some time. This is a manifestation of the net westward drift across the Eastern Great Bahama Bank.

Since no slick was observed in the area of Frazers Hog Cay, it is probable that the water moving off the bank on the ebb in this area does not sink, but rather mixes with the surface waters of the TOTO.

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ACKNOWLEDGMENTS

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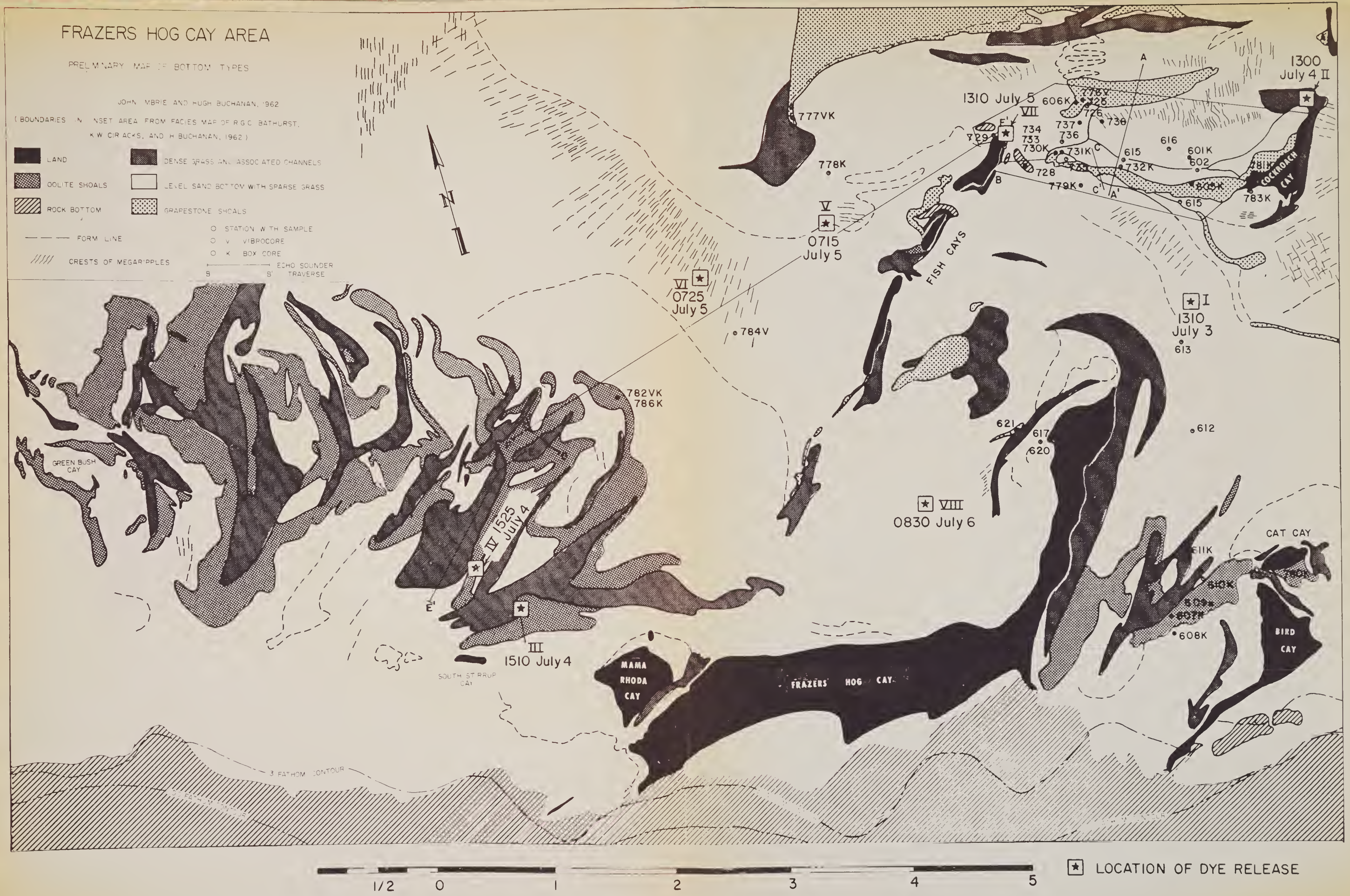
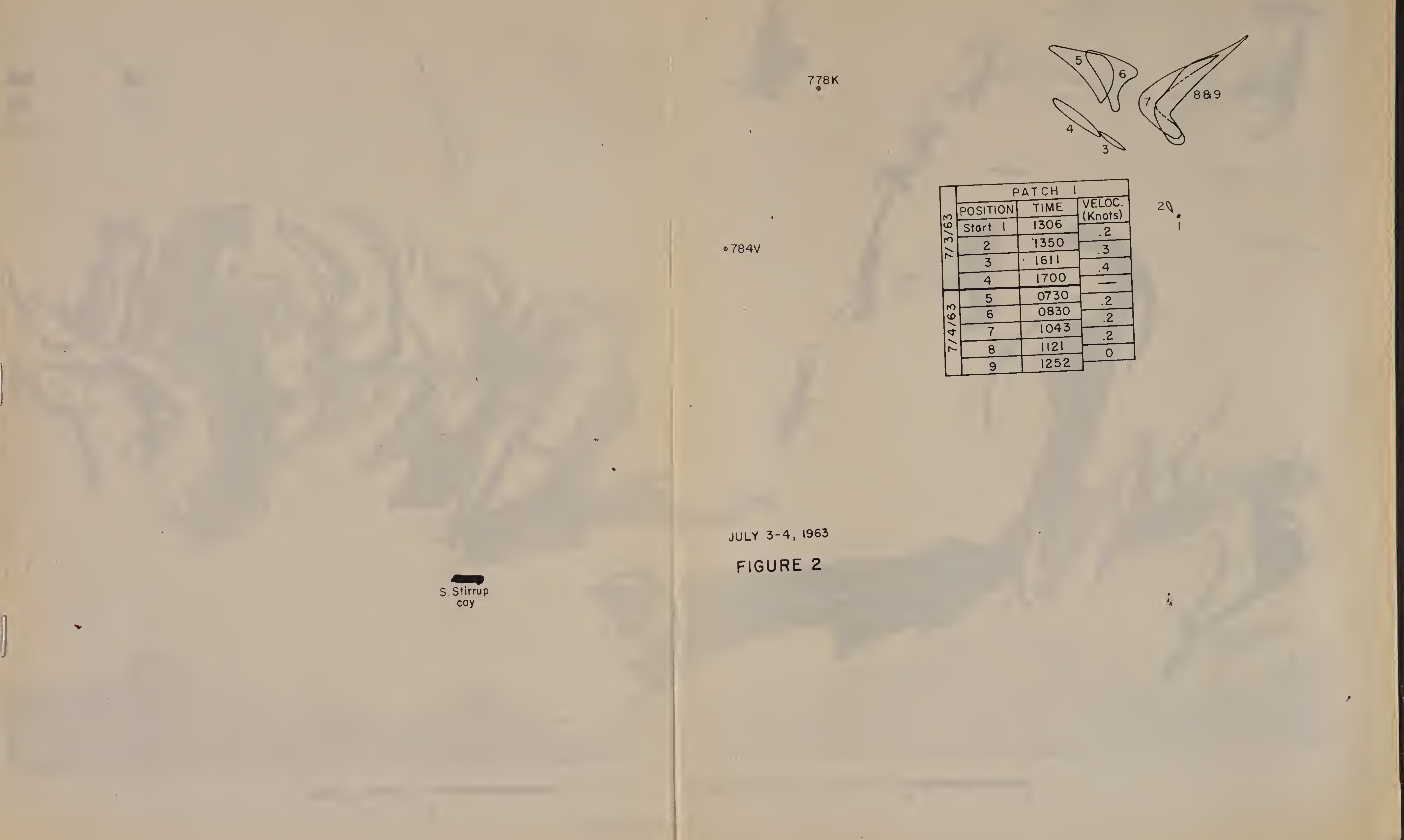

FRAZERS HOG CAY AREA
PRELIMINARY MAP OF BOTTOM TYPES
JOHN IMBRIE AND HUGH BUCHANAN, 1962
(BOUNDARIES IN INSET AREA FROM FACIES MAP OF R.G.C. BATHURST, K.W. CIRACKS, AND H. BUCHANAN, 1962)
LAND
DENSE GRASS AND ASSOCIATED CHANNELS
OOLITE SHOALS
LEVEL SAND BOTTOM WITH SPARSE GRASS
ROCK BOTTOM
GRAPESTONE SHOALS
FORM LINE
STATION WITH SAMPLE
V VIBROCORE
K BOX CORE
CRESTS OF MEGARIPPLES
ECHO SOUNDER TRAVERSE
B
B'
N
777VK
778K
1310 July 5
VII
606K
778V
728
726
738
737
736
734
733
730K
729
F'
731K
C
615
616
601K
602
728
732K
781K
779K
C'
A'
A
805K
615
783K
B
COCKROACH CAY
1300
July 4 II
V
0715
July 5
FISH CAYS
VI
0725
July 5
784V
I
1310
July 3
613
782VK
786K
621
617
620
612
GREEN BUSH CAY
IV 1525 July 4
VIII
0830 July 6
E'
III
1510 July 4
SOUTH STIRRUP CAY
MAMA RHODA CAY
FRAZERS HOG CAY
CAT CAY
611K
610K
609
607K
608K
780K
BIRD CAY
3 FATHOM CONTOUR
1/2
0
1
2
3
4
5
NAUTICAL MILES
LOCATION OF DYE RELEASE

FIGURE I

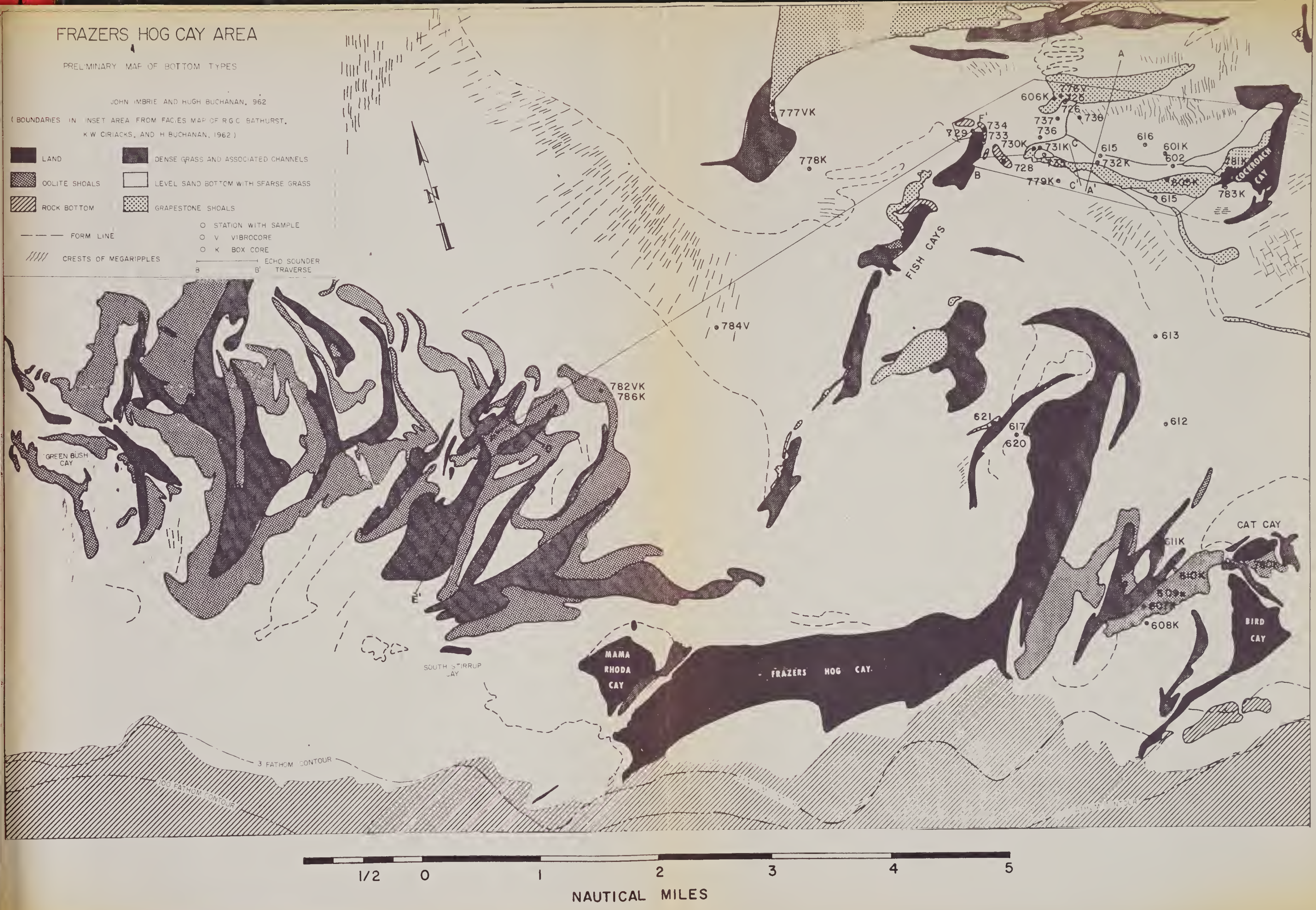
WIND: OCCASIONAL BREEZES LESS THAN 2kts.



	PATCH I		
	POSITION	TIME	VELOC. (Knots)
7/3/63	Start 1	1306	.2
	2	1350	.3
	3	1611	.4
	4	1700	—
7/4/63	5	0730	.2
	6	0830	.2
	7	1043	.2
	8	1121	0
	9	1252	

JULY 3-4, 1963

FIGURE 2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777VK
778K
606K
776V
725
726
737
738
736
E'
734
729
733
730K
731K
C
615
616
601K
602
728
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779K
C'
A'
A
732K
781K
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784V
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782VK
786K
621
617
620
612
GREEN BUSH CAY
E
611K
CAT CAY
780K
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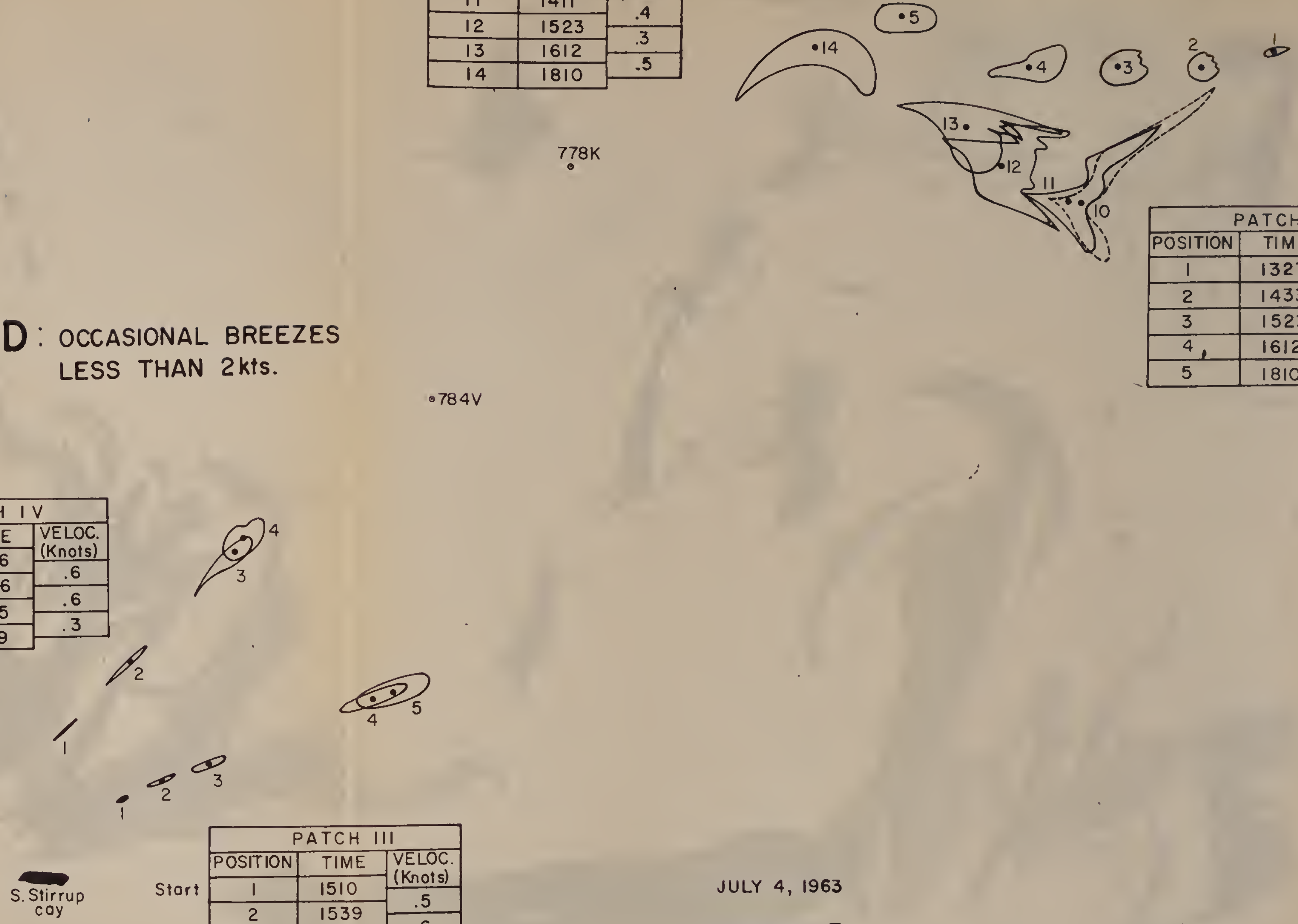
609K
607K
608K
BIRD CAY
MAMA RHODA CAY
FRAZERS HOG CAY
SOUTH STIRRUP CAY
3 FATHOM CONTOUR
100 FATHOM CONTOUR
1/2
0
1
2
3
4
5
NAUTICAL MILES



PATCH I

POSITION	TIME	VELOC. (Knots)
10	1309	.2
11	1411	.4
12	1523	.3
13	1612	.5
14	1810	

PATCH II

POSITION	TIME	VELOC. (Knots)
1	1327	.4
2	1433	.5
3	1523	.6
4	1612	.4
5	1810	

WIND: OCCASIONAL BREEZES LESS THAN 2kts.

PATCH IV

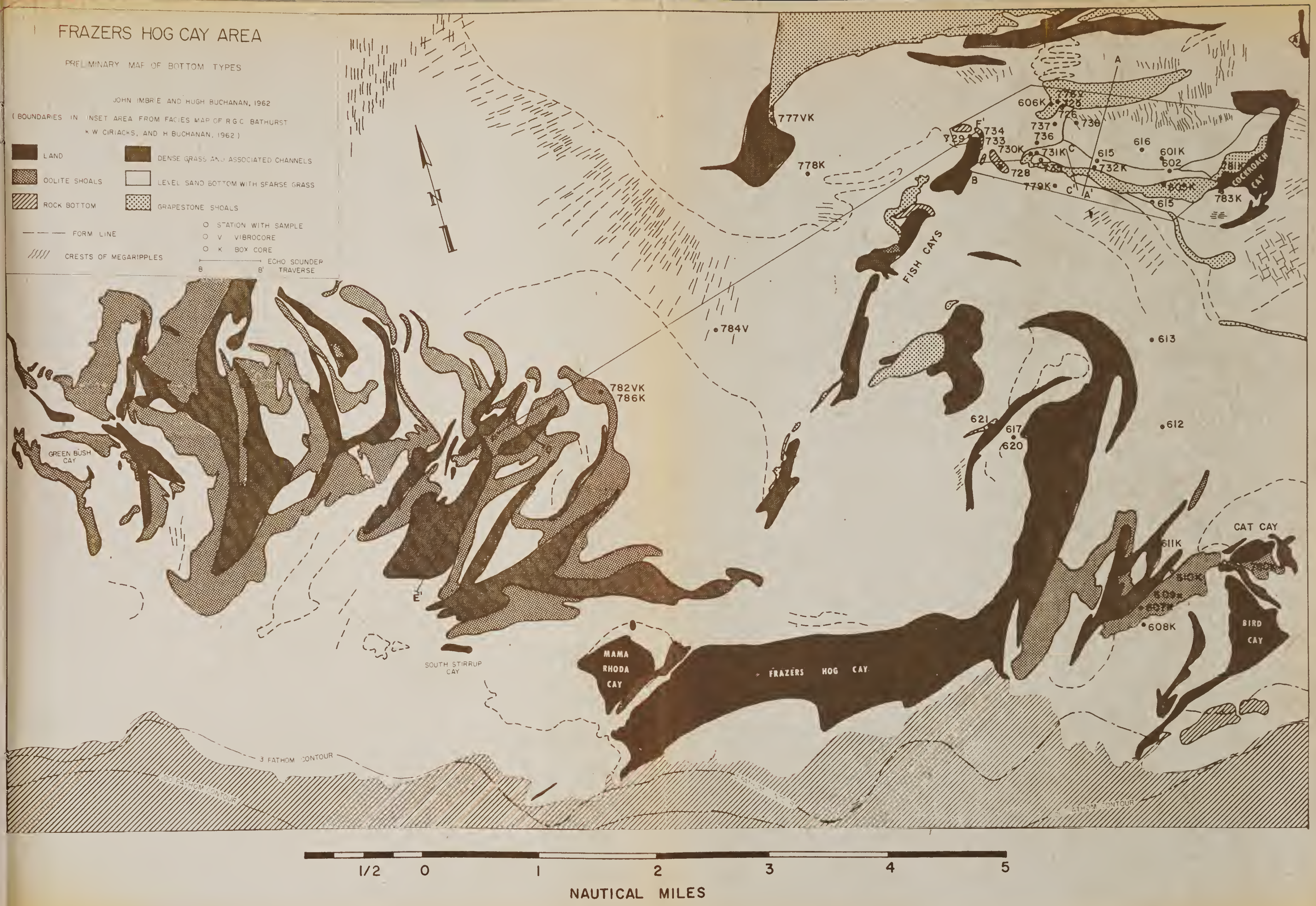
POSITION	TIME	VELOC. (Knots)
1	1536	.6
2	1626	.6
3	1755	.3
4	1819	

PATCH III

POSITION	TIME	VELOC. (Knots)
1	1510	.5
2	1539	.6
3	1606	.6
4	1755	.3
5	1820	

JULY 4, 1963

FIGURE 3



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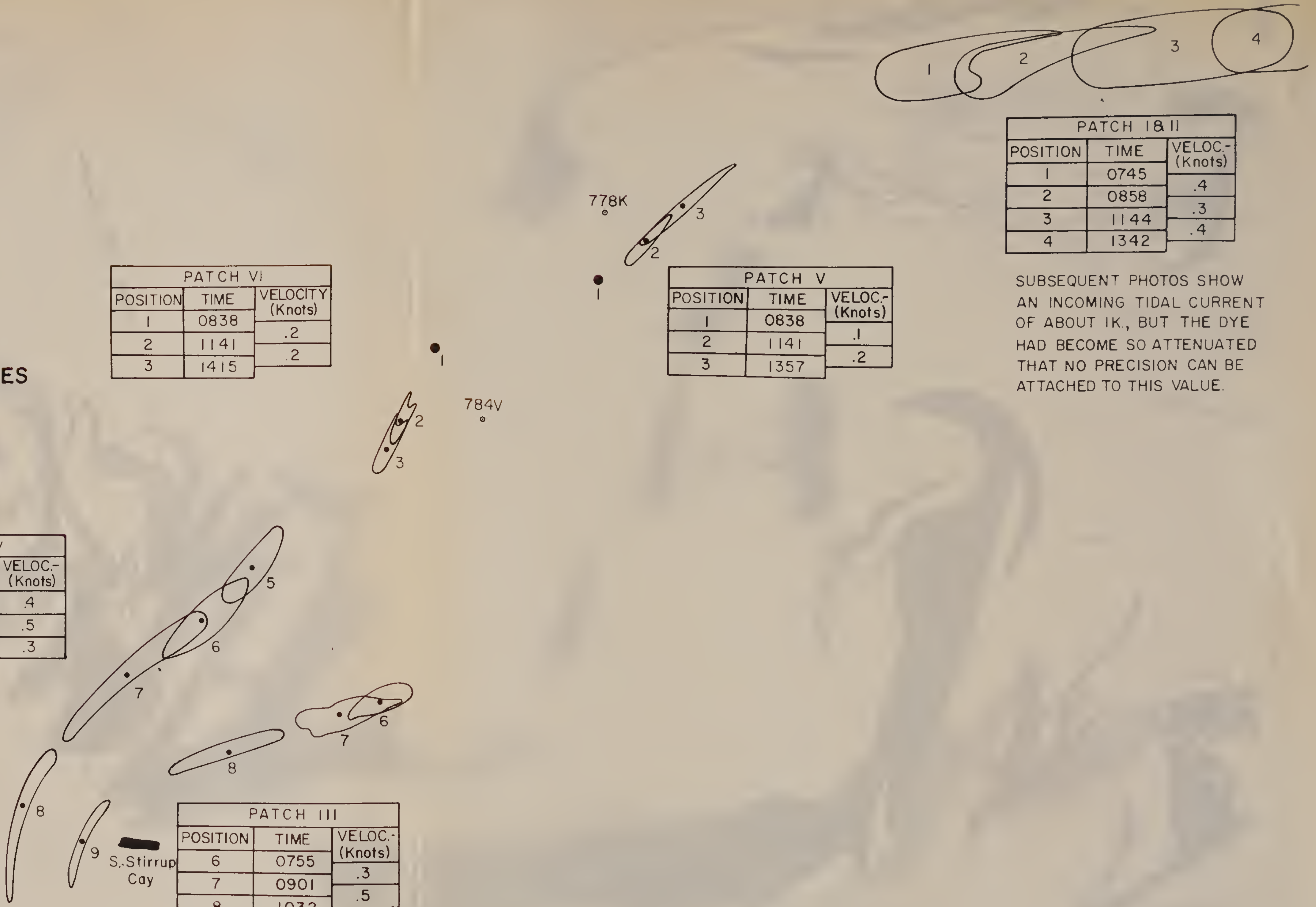
JOHN IMBRIE AND HUGH BUCHANAN, 1962

(BOUNDARIES IN INSET AREA FROM FACIES MAP OF R G C BATHURST K W CIRIACKS, AND H BUCHANAN, 1962)

WIND
OCCASIONAL BREEZES
LESS THAN 2kts.



PATCH I & II		
POSITION	TIME	VELOC.- (Knots)
1	0745	
2	0858	.4
3	1144	.3
4	1342	.4

SUBSEQUENT PHOTOS SHOW AN INCOMING TIDAL CURRENT OF ABOUT 1K., BUT THE DYE HAD BECOME SO ATTENUATED THAT NO PRECISION CAN BE ATTACHED TO THIS VALUE.

PATCH VI		
POSITION	TIME	VELOCITY (Knots)
1	0838	
2	1141	.2
3	1415	.2

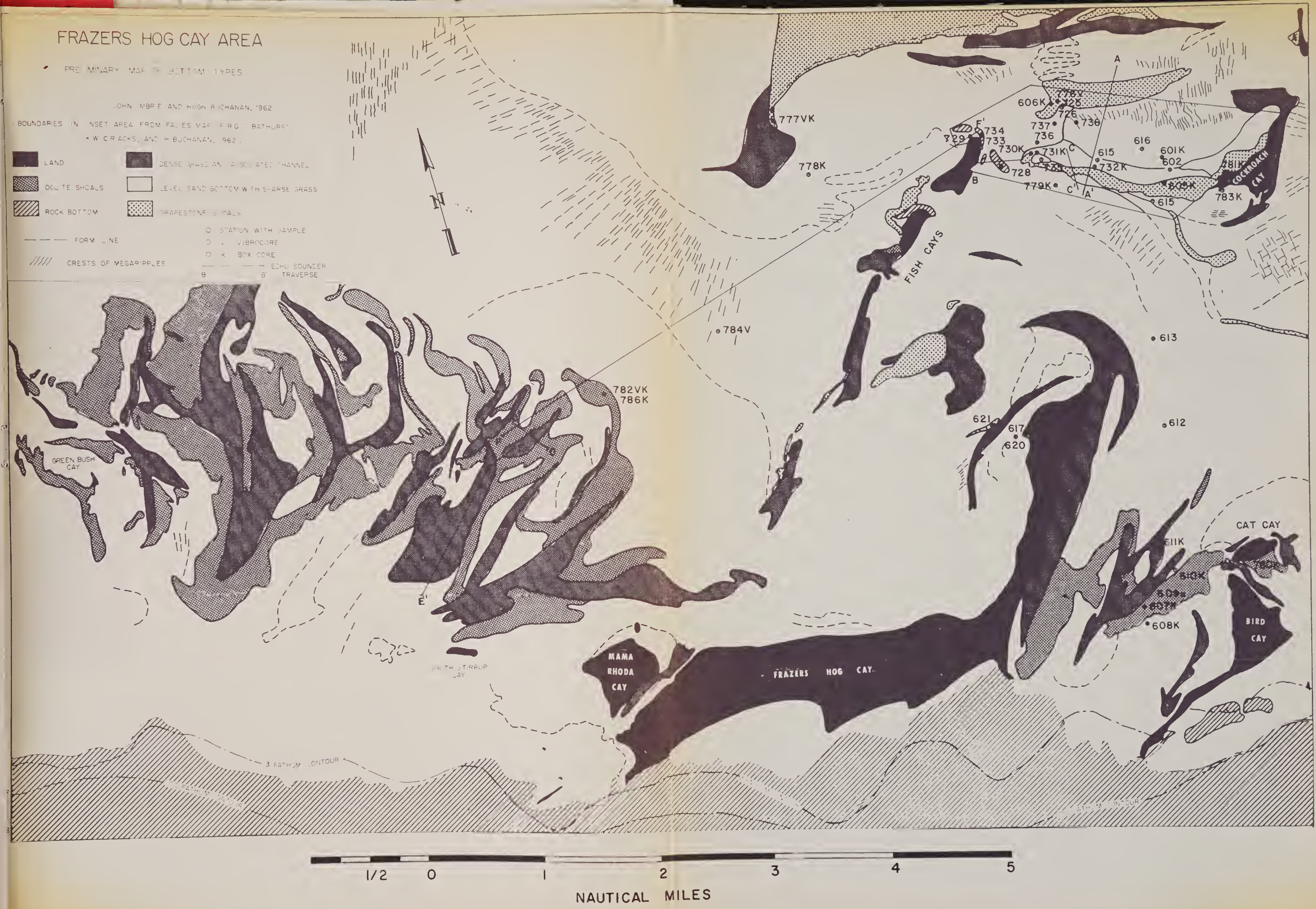
PATCH V		
POSITION	TIME	VELOC.- (Knots)
1	0838	
2	1141	.1
3	1357	.2

PATCH IV		
POSITION	TIME	VELOC.- (Knots)
5	0755	
6	0901	.4
7	1032	.5
8	1350	.3

PATCH III		
POSITION	TIME	VELOC.- (Knots)
6	0755	
7	0901	.3
8	1032	.5
9	1350	.3

JULY 5, 1963

FIGURE 4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1/2
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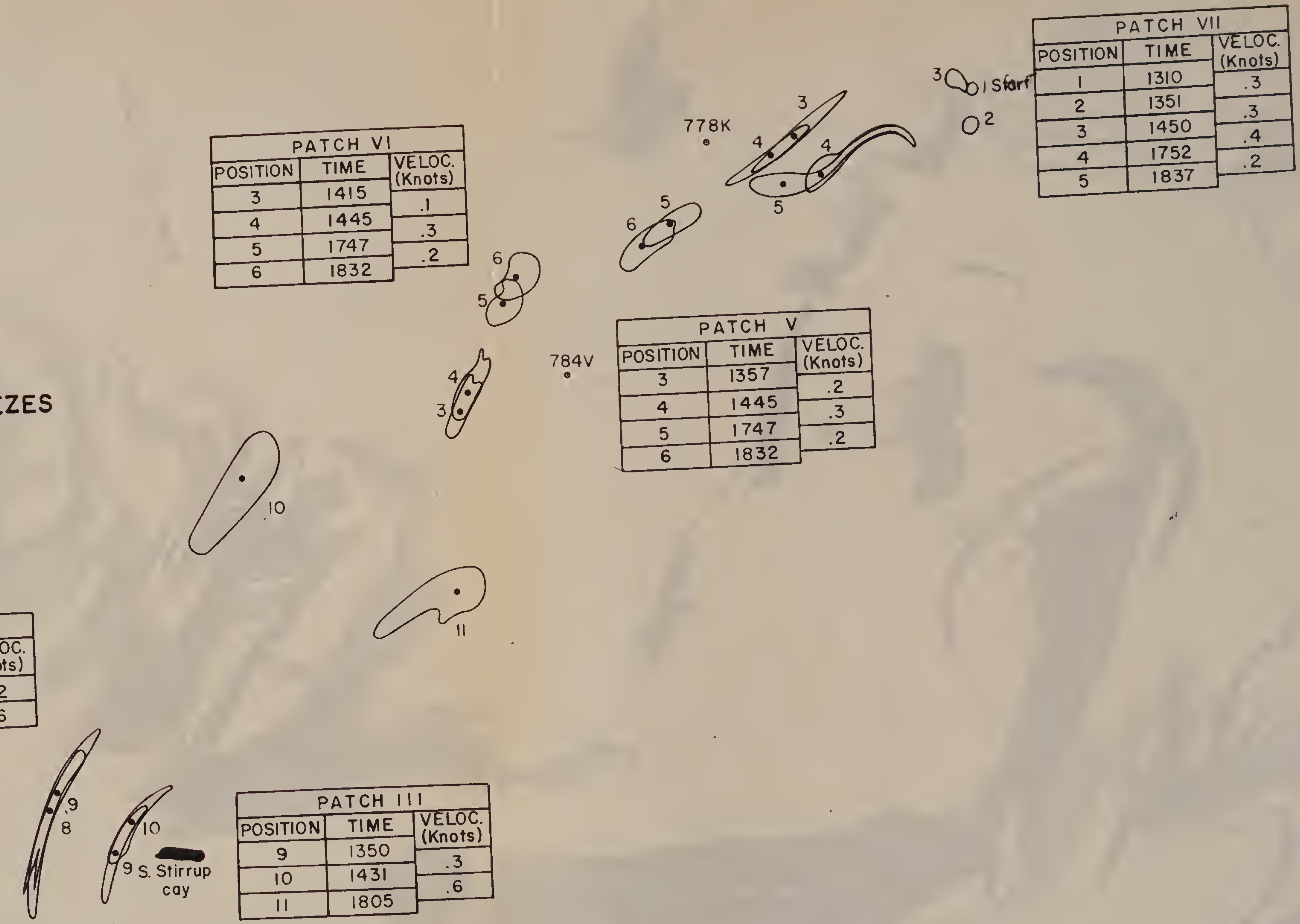
NAUTICAL MILES



WIND

OCCASIONAL BREEZES
LESS THAN 2kts.

PATCH VII		
POSITION	TIME	VELOC. (Knots)
1	1310	.3
2	1351	.3
3	1450	.4
4	1752	.2
5	1837	

PATCH VI		
POSITION	TIME	VELOC. (Knots)
3	1415	.1
4	1445	.3
5	1747	.2
6	1832	

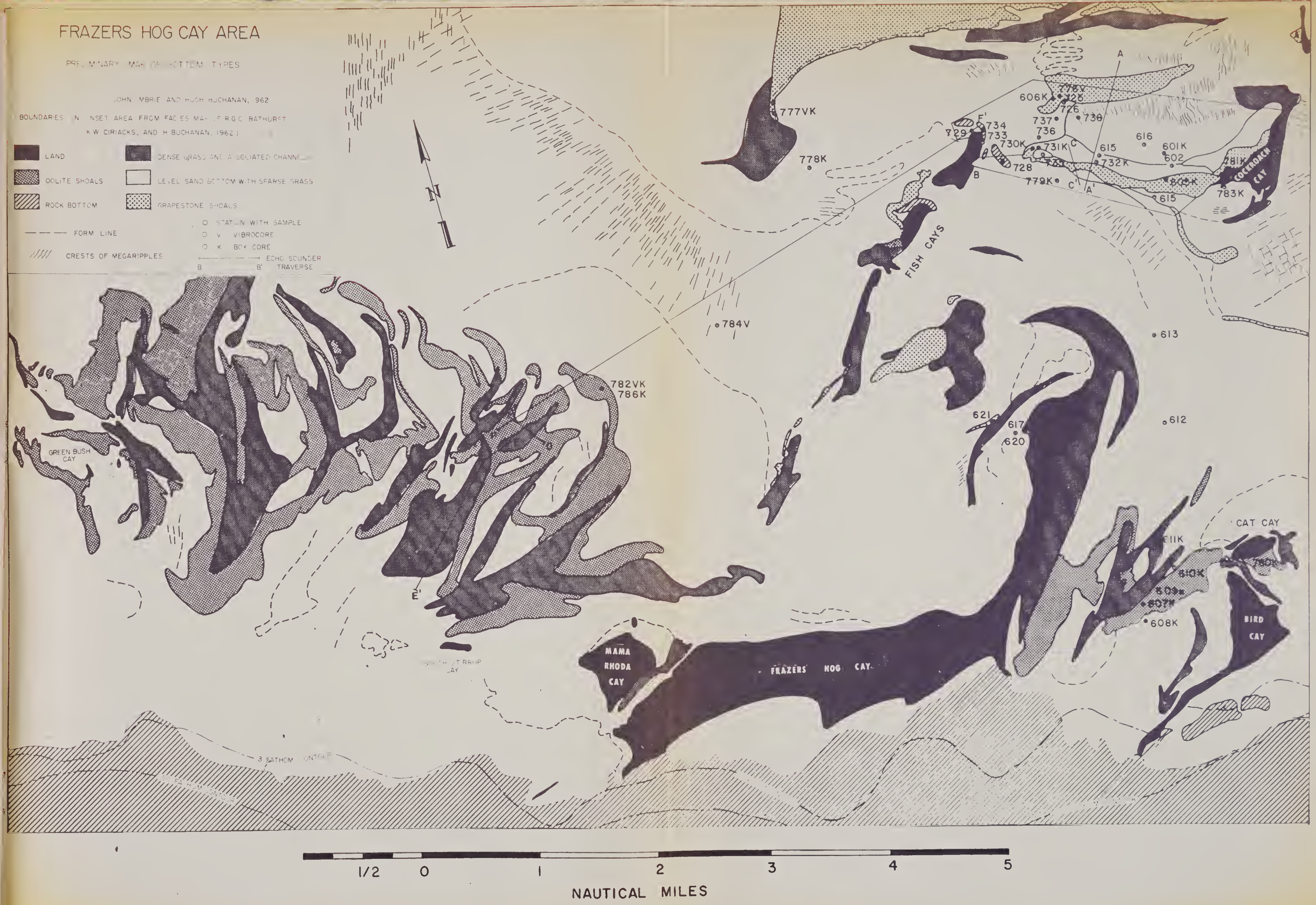
PATCH V		
POSITION	TIME	VELOC. (Knots)
3	1357	.2
4	1445	.3
5	1747	.2
6	1832	

PATCH IV		
POSITION	TIME	VELOC. (Knots)
8	1350	.2
9	1431	.6
10	1805	

PATCH III		
POSITION	TIME	VELOC. (Knots)
9	1350	.3
10	1431	.6
11	1805	

JULY 5, 1963

FIGURE 5



FRAZERS HOG CAY AREA

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JOHN MBRIE AND HUGH BUCHANAN, 962

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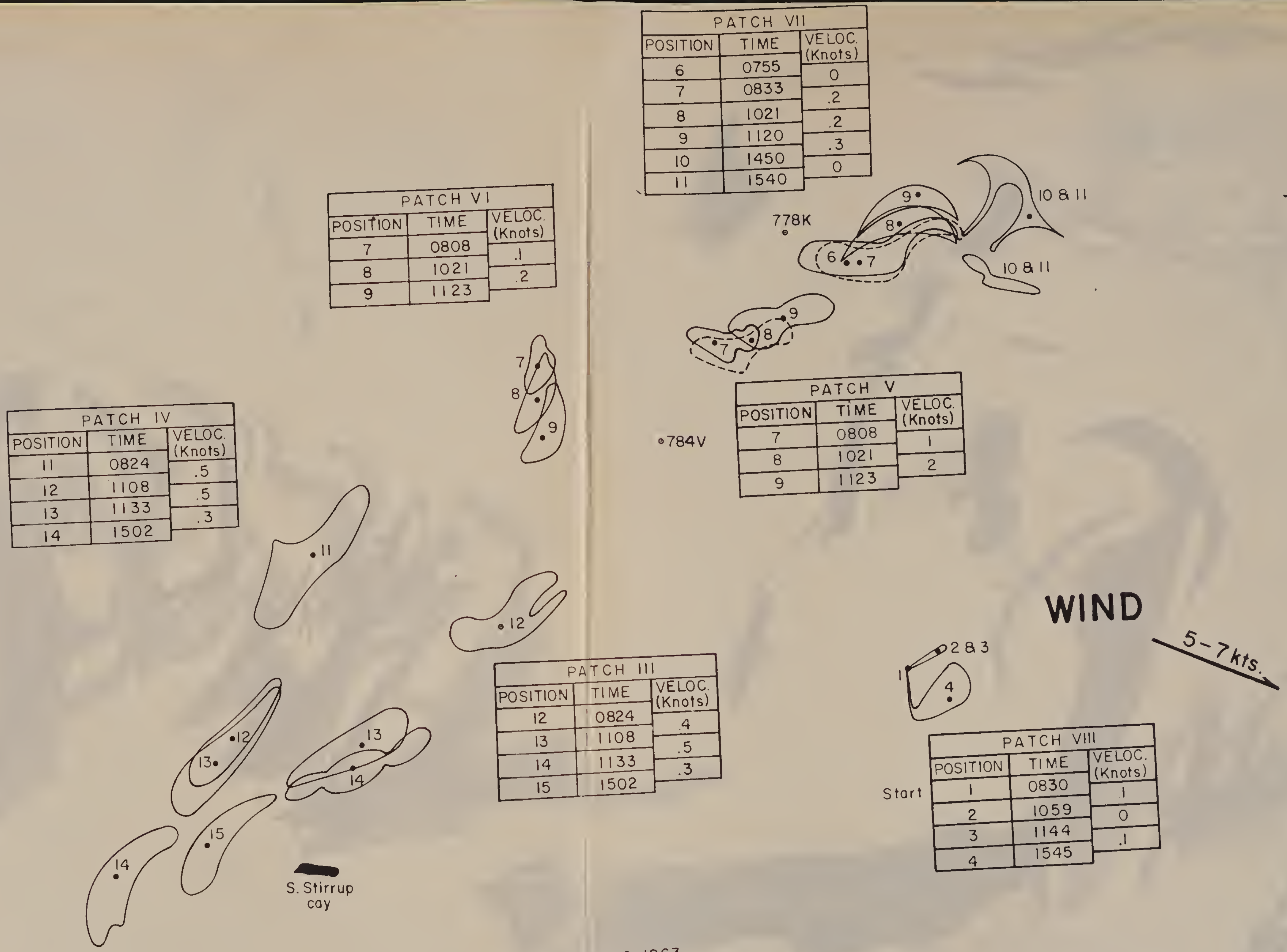


PATCH VII

POSITION	TIME	VELOC. (Knots)
6	0755	0
7	0833	.2
8	1021	.2
9	1120	.3
10	1450	0
11	1540	

PATCH VI

POSITION	TIME	VELOC. (Knots)
7	0808	.1
8	1021	.2
9	1123	

PATCH V

POSITION	TIME	VELOC. (Knots)
7	0808	1
8	1021	.2
9	1123	

PATCH IV

POSITION	TIME	VELOC. (Knots)
11	0824	.5
12	1108	.5
13	1133	.3
14	1502	

PATCH III

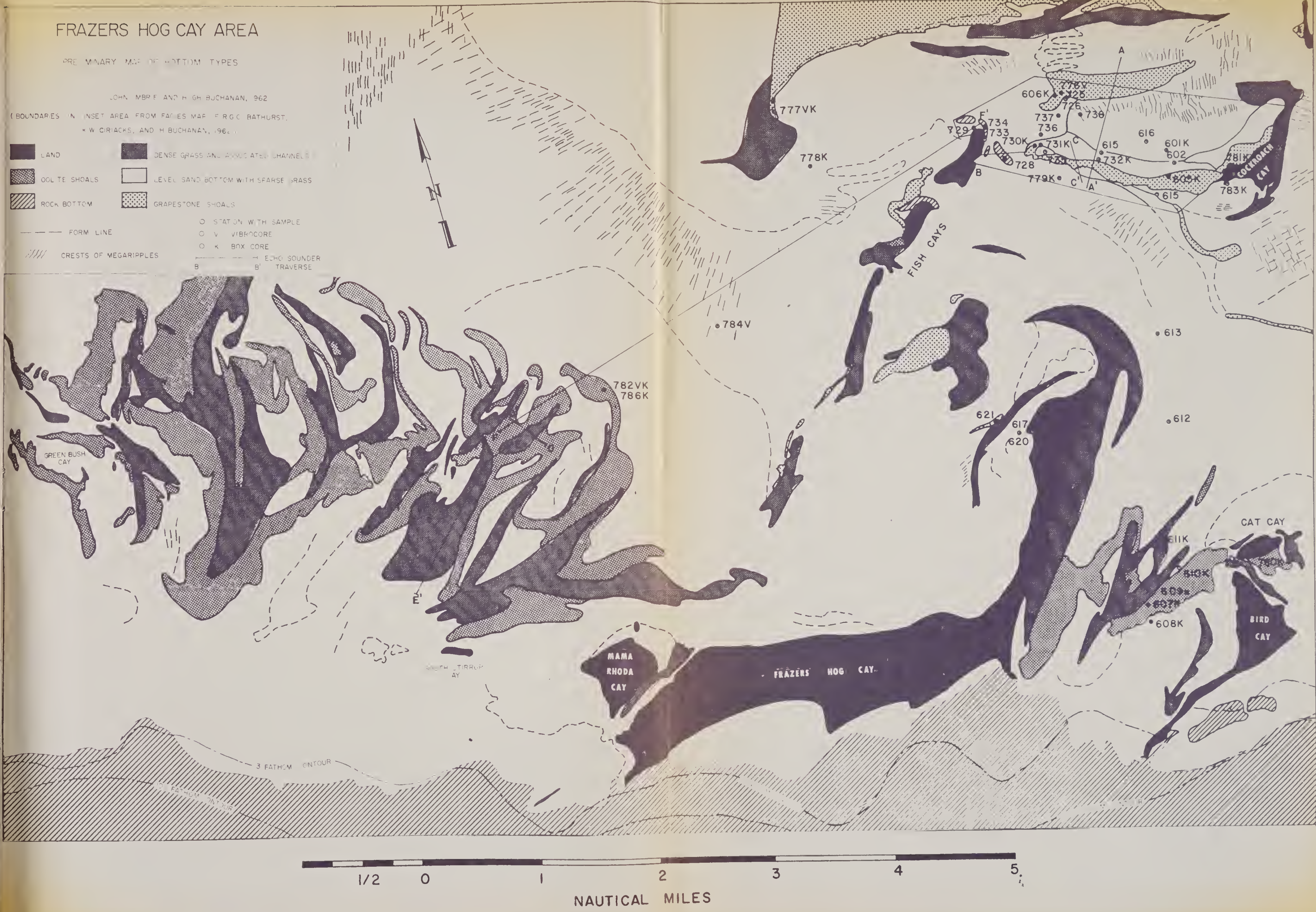
POSITION	TIME	VELOC. (Knots)
12	0824	.4
13	1108	.5
14	1133	.3
15	1502	

PATCH VIII

POSITION	TIME	VELOC. (Knots)
1	0830	1
2	1059	0
3	1144	.1
4	1545	

JULY 6, 1963

FIGURE 6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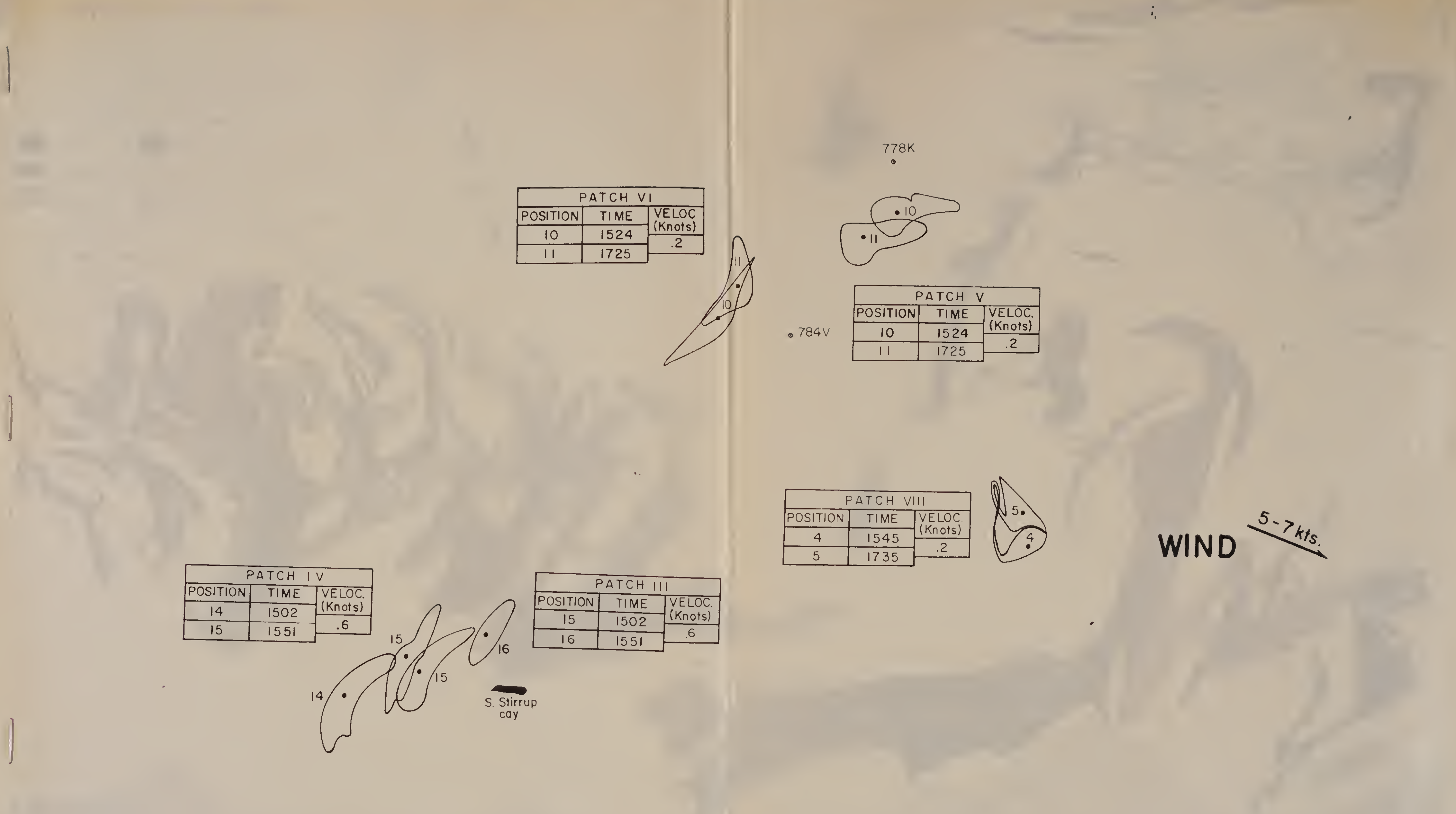
CRESTS OF MEGARIPPLES
STATION WITH SAMPLE
V VIBROCORE
K BOX CORE
B B' ECHO SOUNDER TRAVERSE
N
777VK
778K
784V
782VK
786K
FISH CAYS
606K
776V
725
726
737
738
734
733
729
736
730K
731K
728
779K
B
E'
C
C'
A
A'
616
615
601K
602
732K
605K
615
781K
783K
COCKROACH CAY
613
612
621
617
620
611K
610K
609K
607K
608K
CAT CAY
BIRD CAY
GREEN BUSH CAY
E'
MAMA RHODA CAY
FRAZERS HOG CAY
SOUTH STIRRUP CAY
3 FATHOM CONTOUR
5 FATHOM CONTOUR
1/2
0
1
2
3
4
5
NAUTICAL MILES



PATCH VI		
POSITION	TIME	VELOC (Knots)
10	1524	.2
11	1725	

PATCH V		
POSITION	TIME	VELOC. (Knots)
10	1524	.2
11	1725	

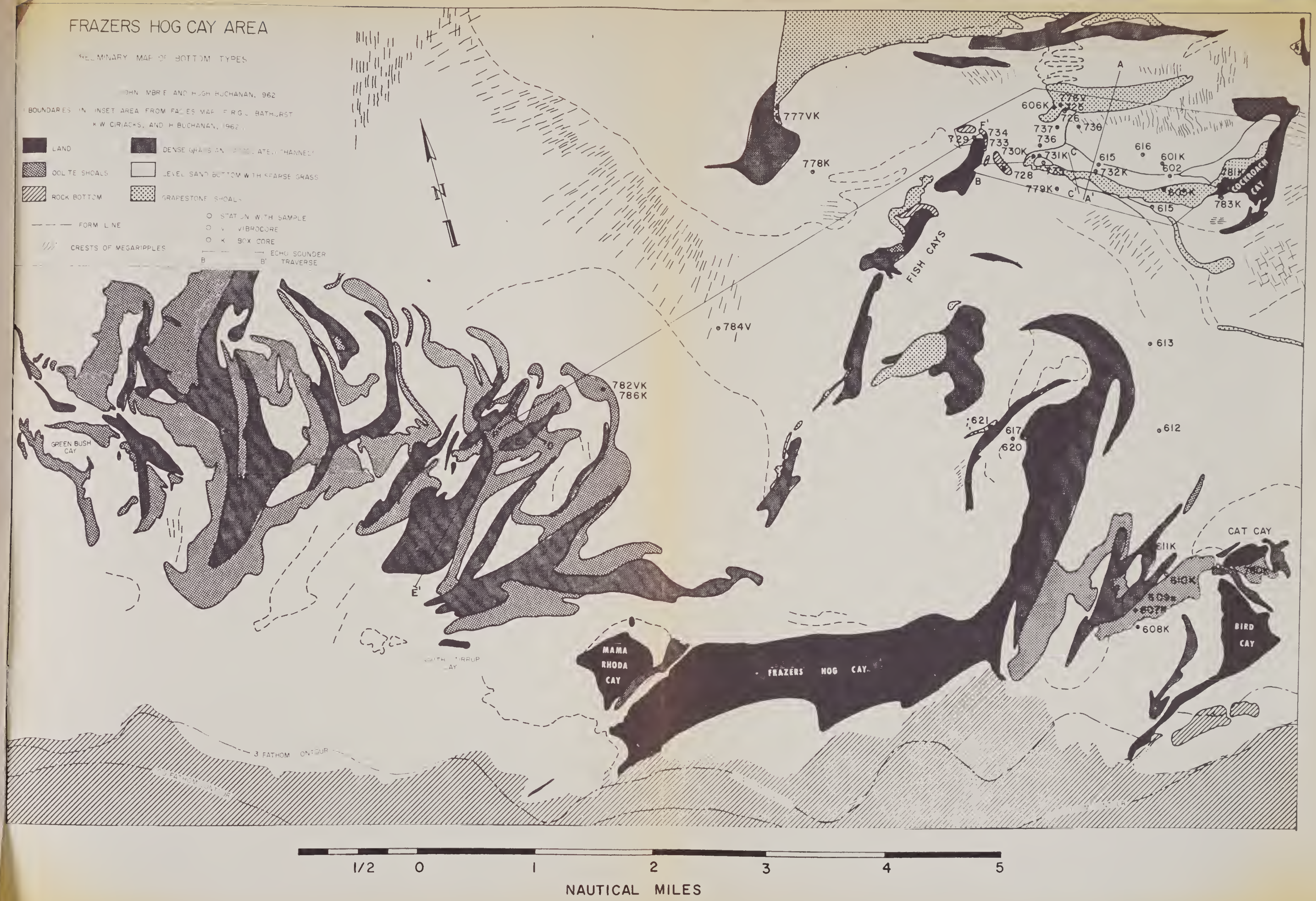
PATCH VIII		
POSITION	TIME	VELOC. (Knots)
4	1545	.2
5	1735	

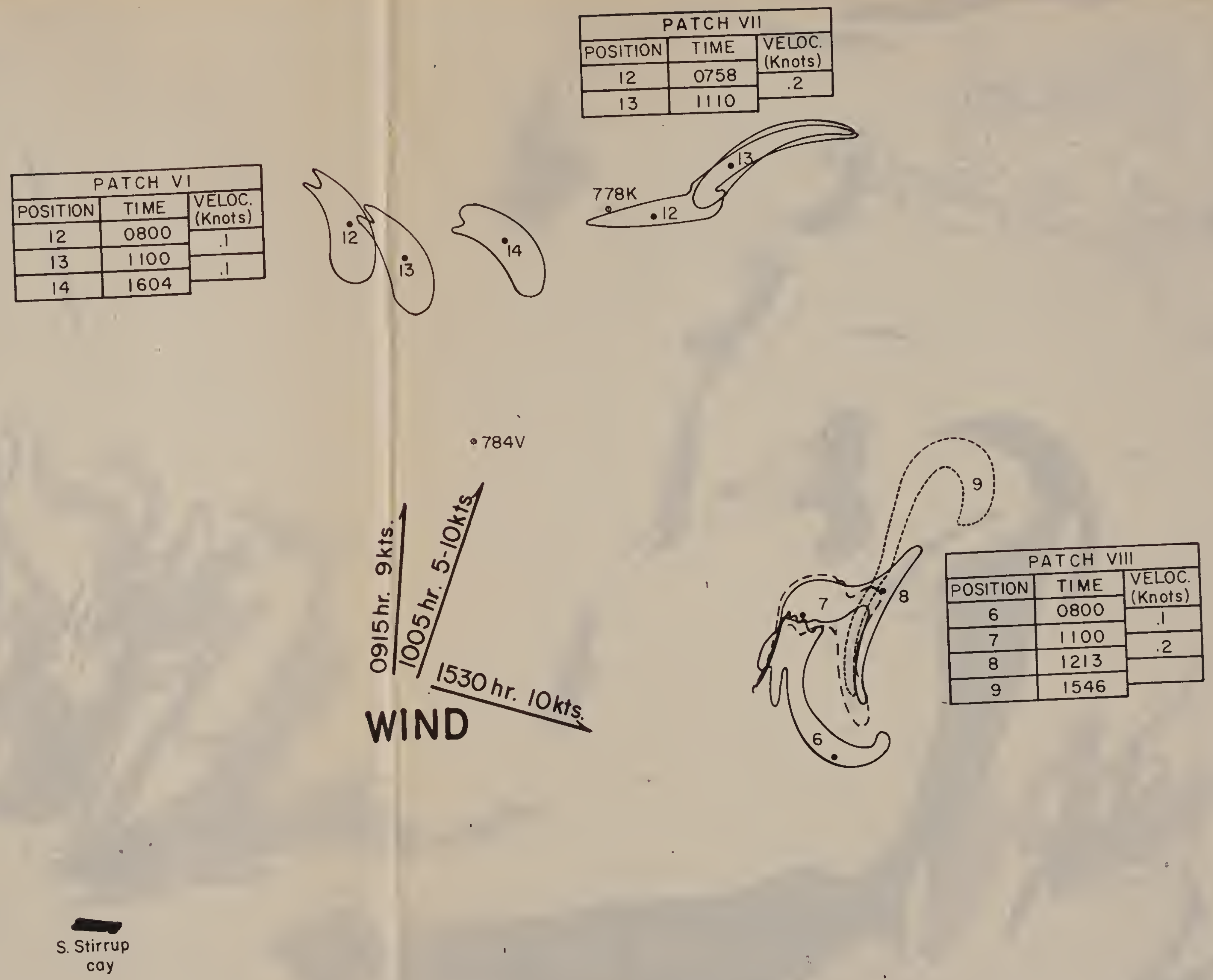
PATCH IV		
POSITION	TIME	VELOC. (Knots)
14	1502	.6
15	1551	

PATCH III		
POSITION	TIME	VELOC. (Knots)
15	1502	.6
16	1551	

JULY 6, 1963

FIGURE 7


FRAZERS HOG CAY AREA
PRELIMINARY MAP OF BOTTOM TYPES
JOHN IMBRIE AND HUGH BUCHANAN, 1962
(BOUNDARIES IN INSET AREA FROM FACIES MAP OF R.G.C. BATHURST
K.W. CIRIACKS, AND H. BUCHANAN, 1962.)
LAND
OOLITE SHOALS
ROCK BOTTOM
DENSE GRASS AND ASSOCIATED CHANNELS
LEVEL SAND BOTTOM WITH SPARSE GRASS
GRAPESTONE SHOALS
FORM LINE
CRESTS OF MEGARIPPLES
STATION WITH SAMPLE
V VIBROCORE
K BOX CORE
B B' ECHO SOUNDER TRAVERSE
N
777VK
778K
784V
782VK
786K
GREEN BUSH CAY
E
E'
SOUTH STIRRUP CAY
MAMA RHODA CAY
FRAZERS HOG CAY
3 FATHOM CONTOUR
FISH CAYS
729
734
733
730K
728
B
606K
778V
725
726
737
736
738
731K
733
C
C'
A
A'
779K
615
732K
616
601K
602
600K
615
781K
783K
COCKROACH CAY
613
612
621
617
620
CAT CAY
611K
610K
609K
607K
608K
BIRD CAY
1/2
0
1
2
3
4
5
NAUTICAL MILES



PATCH VI

POSITION	TIME	VELOC. (Knots)
12	0800	.1
13	1100	.1
14	1604	

PATCH VII

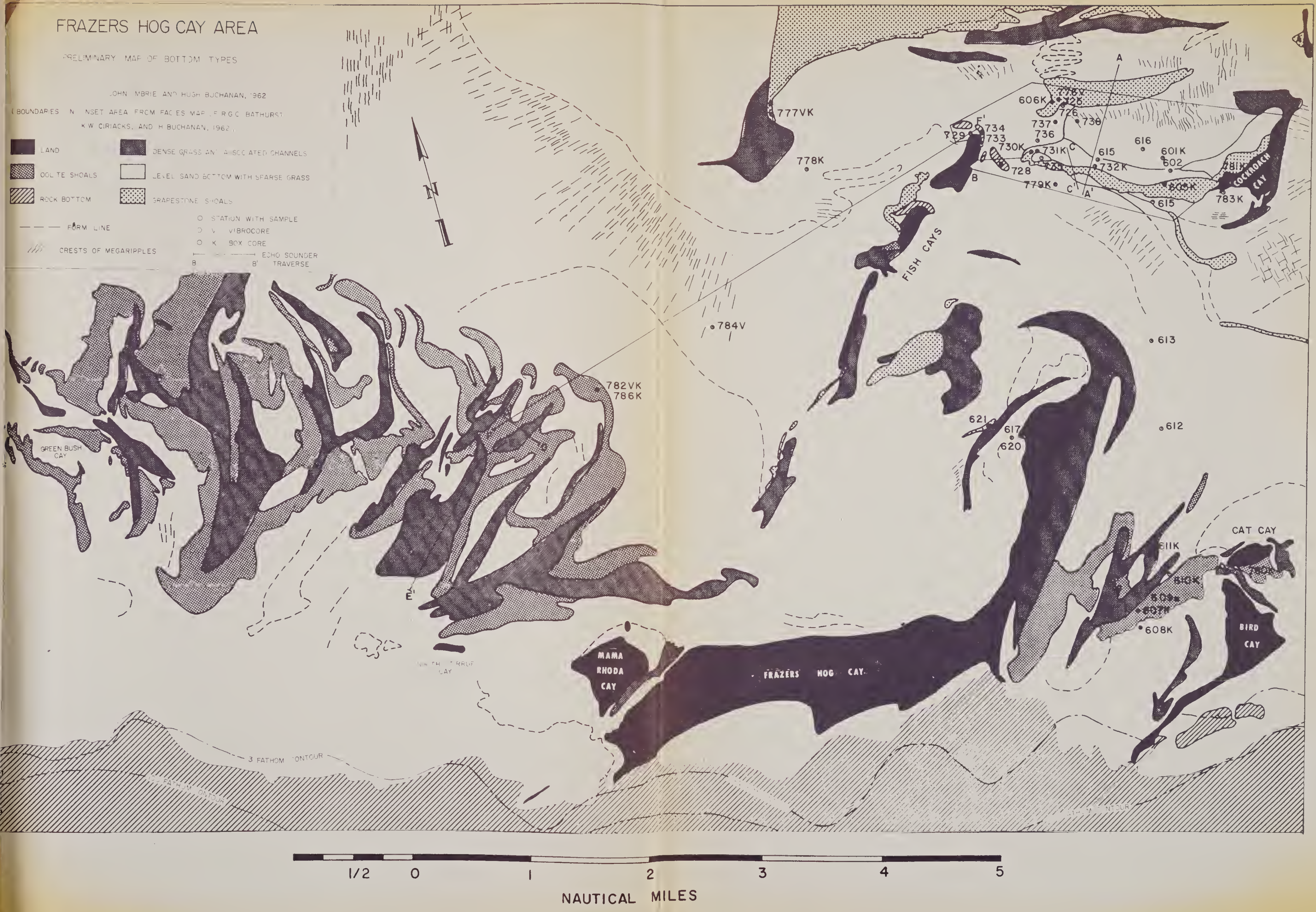
POSITION	TIME	VELOC. (Knots)
12	0758	.2
13	1110	

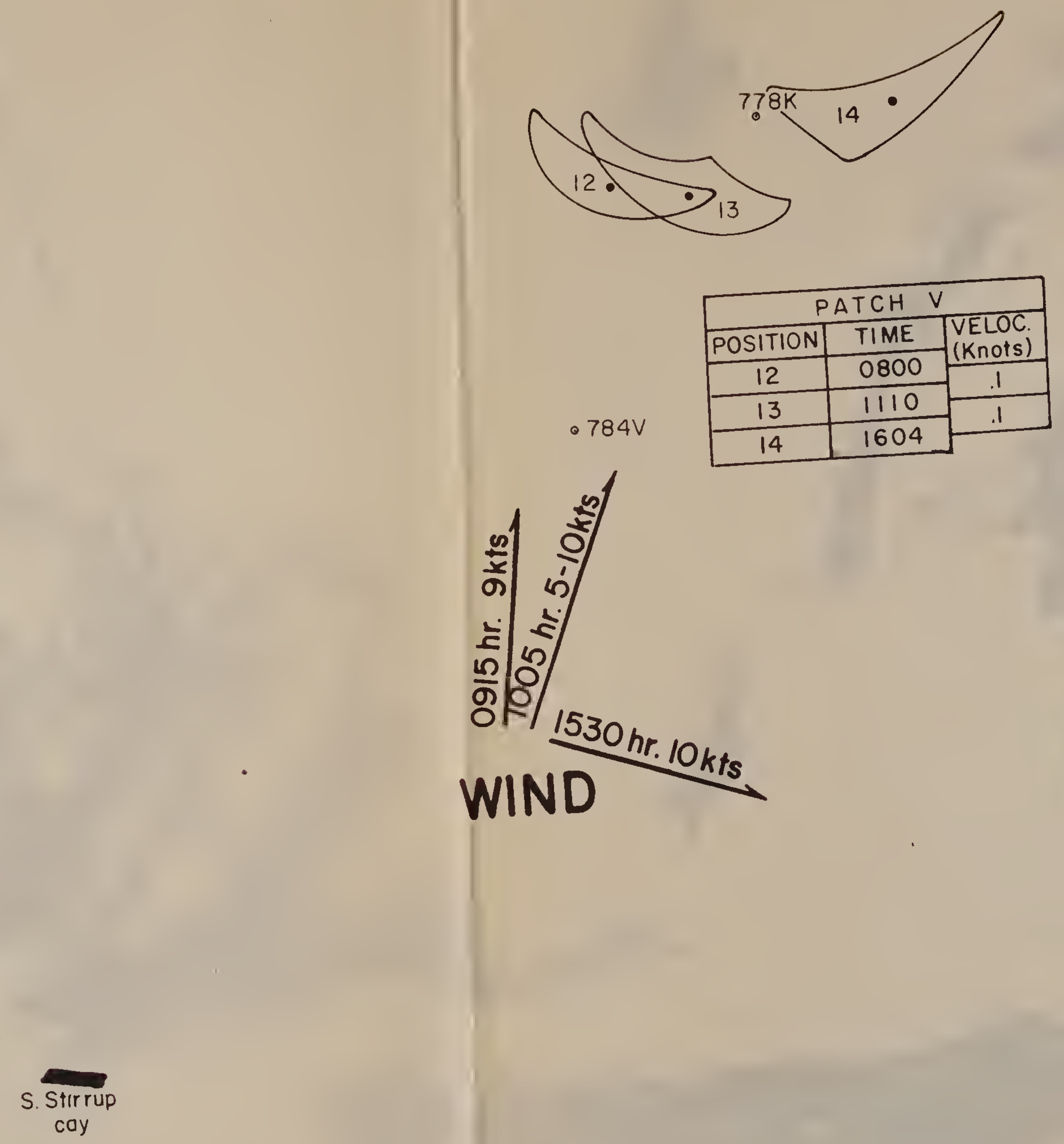
PATCH VIII

POSITION	TIME	VELOC. (Knots)
6	0800	.1
7	1100	.2
8	1213	
9	1546	

JULY 7, 1963

FIGURE 8

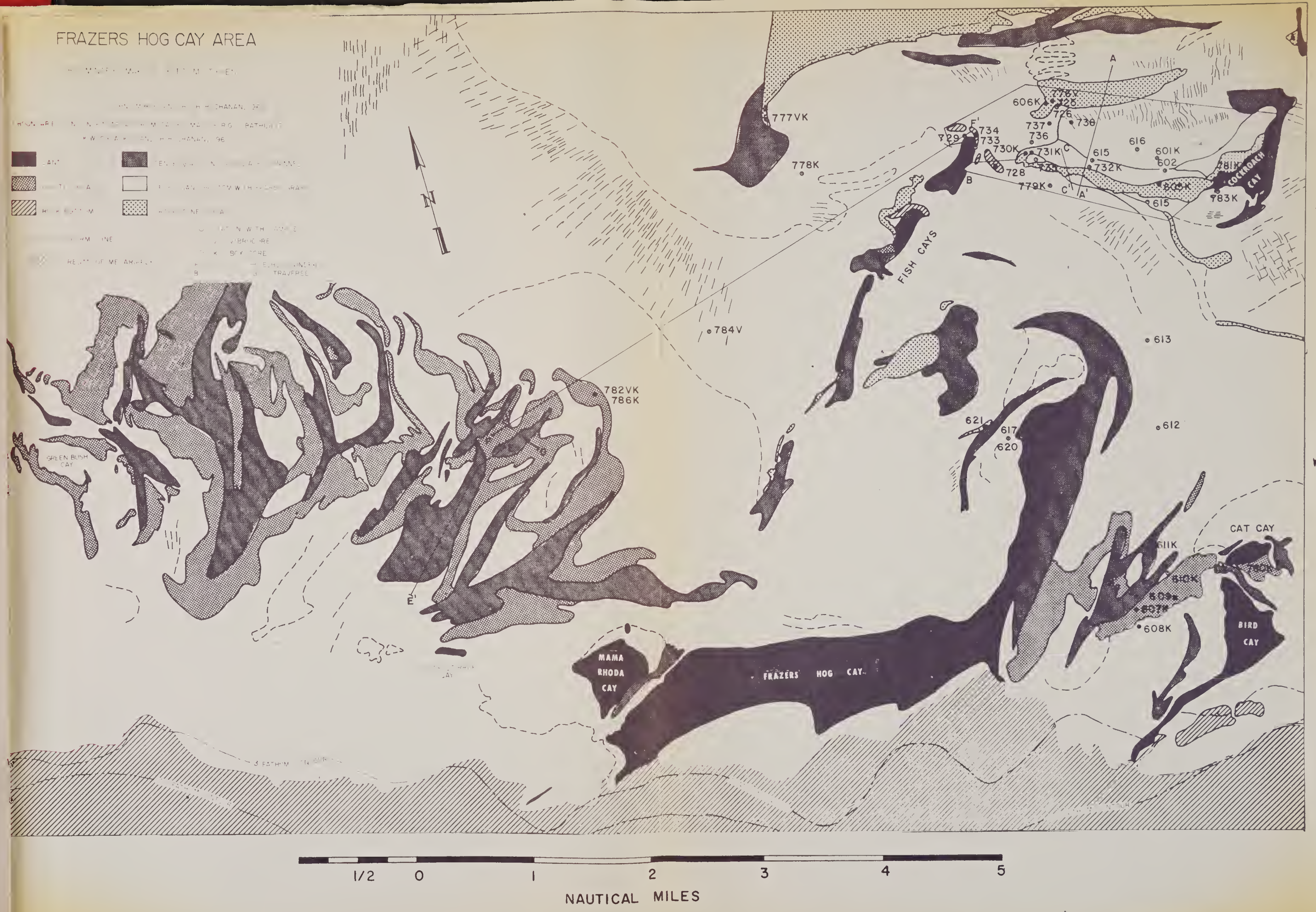

FRAZERS HOG CAY AREA
PRELIMINARY MAP OF BOTTOM TYPES
JOHN IMBRIE AND HUGH BUCHANAN, 1962
(BOUNDARIES IN INSET AREA FROM FACIES MAP OF R.G.C. BATHURST, K.W. CIRIACKS, AND H. BUCHANAN, 1962.)
LAND
DENSE GRASS AND ASSOCIATED CHANNELS
OOLITE SHOALS
LEVEL SAND BOTTOM WITH SPARSE GRASS
ROCK BOTTOM
GRAPESTONE SHOALS
FORM LINE
STATION WITH SAMPLE
V VIBROCORE
K BOX CORE
CRESTS OF MEGARIPPLES
ECHO SOUNDER TRAVERSE
B
B'
N
777VK
778K
A
606K
778V
726
726
737
738
736
F'
734
729
733
730K
731K
C
615
616
601K
602
728
731
732K
B
779K
C'
A'
781K
COCKROACH CAY
805K
783K
615
FISH CAYS
784V
613
782VK
786K
621
617
620
612
GREEN BUSH CAY
E
611K
CAT CAY
810K
609
607K
608K
BIRD CAY
NORTH ... CAY
MAMA RHODA CAY
FRAZERS HOG CAY
3 FATHOM CONTOUR
FATHOM CONTOUR
CONTOUR
1/2
0
1
2
3
4
5
NAUTICAL MILES

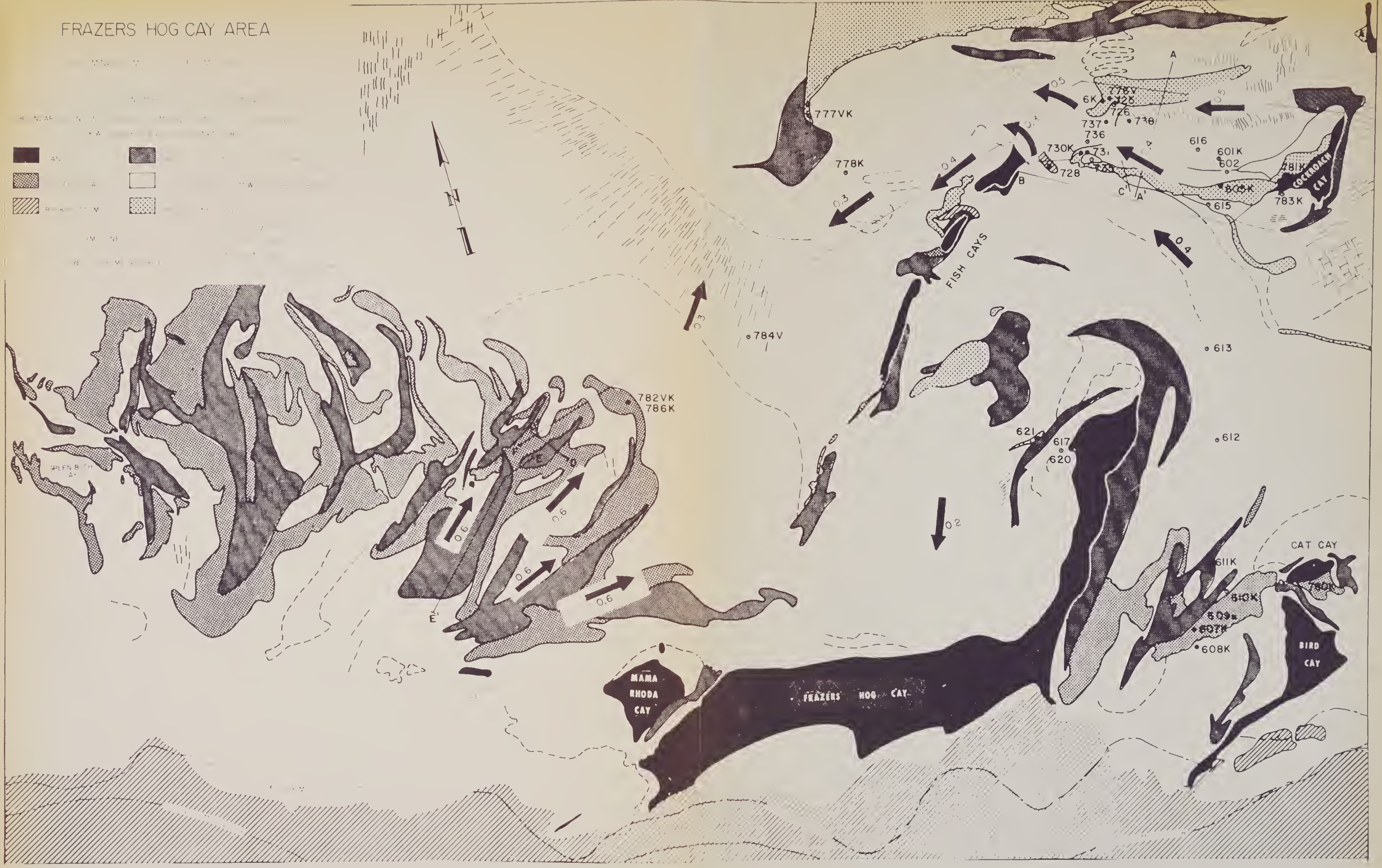


PATCH V		
POSITION	TIME	VELOC. (Knots)
12	0800	.1
13	1110	.1
14	1604	

JULY 7, 1963

FIGURE 9

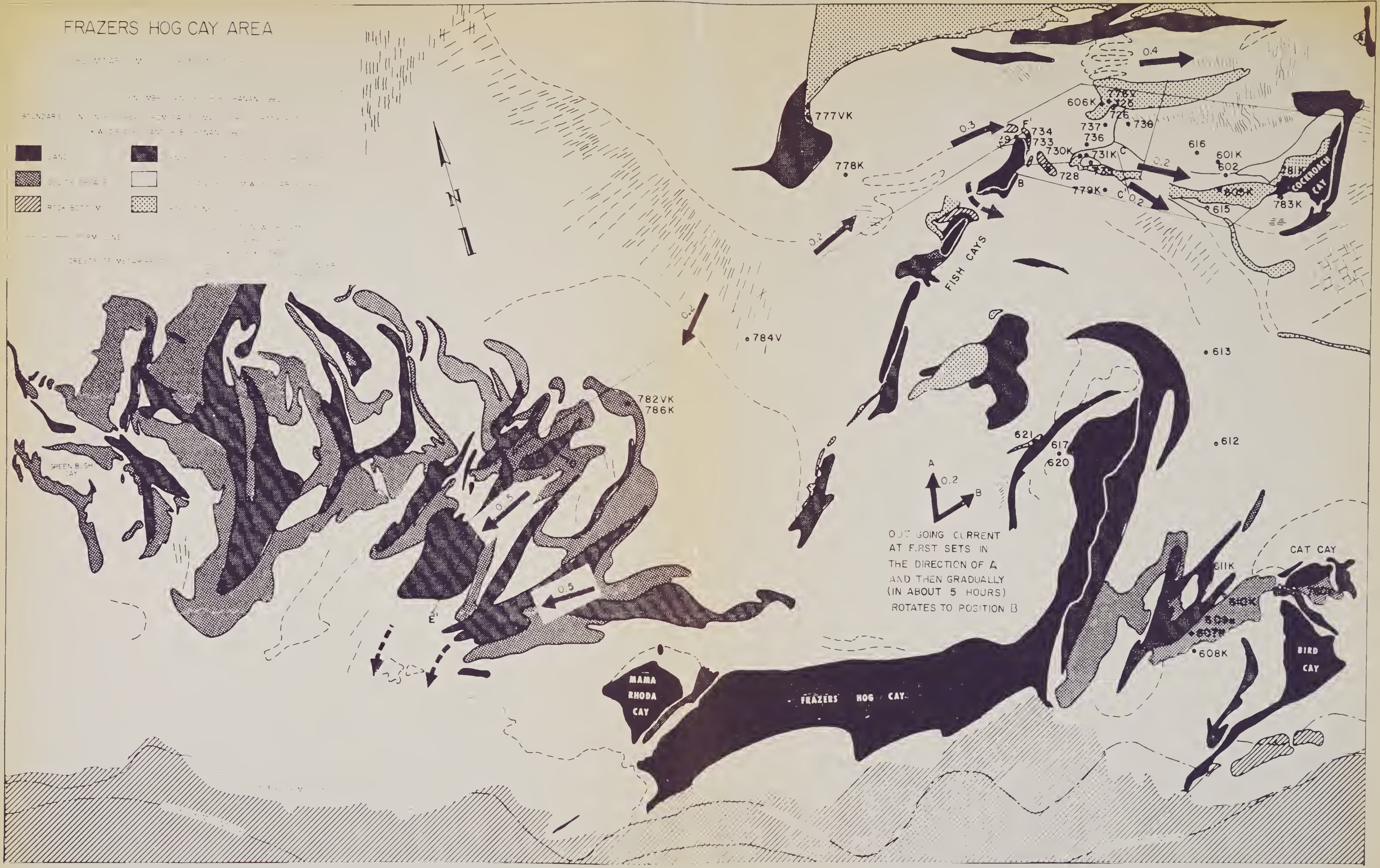

FRAZERS HOG CAY AREA
CHANAN, 196
BATHURST
LAND
TRAVERSE
VIBROCORE
BOX CORE
FATHOM LINE
N
777VK
778K
606K
776V
726
737
738
736
734
733
729
E'
B
730K
731K
728
735
779K
C
C'
A
A'
615
616
601K
602
732K
781K
COCKROACH CAY
605K
783K
615
FISH CAYS
784V
782VK
786K
613
612
621
617
620
GREEN BUSH CAY
E
CAT CAY
611K
610K
780K
609
607K
608K
BIRD CAY
MAMA RHODA CAY
FRAZERS HOG CAY
3 FATHOM
1/2
0
1
2
3
4
5
NAUTICAL MILES



FLOODING TIDAL CURRENTS

VELOCITIES IN KNOTS

FIGURE 10



EBBING TIDAL CURRENTS

VELOCITIES IN KNOTS

FIGURE II

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